This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

QB
88
.N79

A 415375

ARTES
VERITAS
SCIENTIA
LIBRARY OF THE
UNIVERSITY OF MICHIGAN
E PLURIBUS UNUM
QUAERIS PENINSULAM AMOENAM
CIRCUMSPICE

THE TELESCOPE.

THE PRINCIPLES INVOLVED IN THE CONSTRUCTION OF REFRACTING AND REFLECTING TELESCOPES.

BY

THOMAS NOLAN, B.S.

REPRINTED FROM VAN NOSTRAND'S MAGAZINE.

NEW YORK:
D. VAN NOSTRAND, PUBLISHER,
23 MURRAY AND 27 WARREN STREET.
1881.

PREFACE.

The following discussion of the elementary optical principles of the telescope was written two years ago, and is now published without alteration or additions.

From the nature of the subject, the writer can, of course, claim no originality, except for the *form* in which he presents the material, collected and condensed from various treatises on optics.

CONTENTS.

The Optical Principles Involved in the the Construction of the Telescope.. 9

I. The Simple Refracting Telescope..... 10

1. The Galilean Telescope..... 15

2. The Astronomical Telescope..... 19

3. The Terrestrial Telescope..... 23

II. The Reflecting Telescope..... 26

1. Different Forms..... 32

(1.) The Herschelian Telescope..... 32

(2.) The Gregorian Telescope..... 34

(3.) The Cassegrainian Telescope.... 36

(4.) The Newtonian Telescope..... 38

2. Spherical Aberration by Reflection... 40

III. The Compound Refracting, or Modern Aplanatic and Achromatic Telescope..... 42

1. The Objective..... 42

(1.) Spherical Aberration by Refraction..... 42

(2.) Chromatic Aberration..... 49

(3.) Secondary Spectrum 61

(4.) Double Reflection.. 63

2. The Eye-Piece 64
(1.) The Huyghenian Eye-Piece..... 65
(2.) The Ramsden Eye-Piece..... 69
(3.) The Erecting or Day Eye-Piece.. 69

IV. Comparison of Refracting and Reflecting Telescopes..... 71

THE TELESCOPE.

The Telescope is certainly one of the noblest monuments of human genius, and its invention will always be considered as among the most remarkable in the whole circle of human knowledge. It is a work, in which, by following unconsciously the plan of nature in the formation of the eye, we have come the nearest to the construction of a new organ of sense, and by means of which, we have extended our views and researches far beyond the limits of our own globe—that sphere which nature seemed to have designed for our inquiries. Enabling us to penetrate into the immensity of space, and to become, as it were, familiar with other worlds placed at almost immeasurable distances from us, the telescope has revealed an

infinitude of celestial bodies, whose existence must forever have remained unknown to us, but for its invention. Its history, like that of every complicated instrument, has been a history of improvements. The question of the origin of the invention, although abundantly inquired into, has never met with a satisfactory answer; and the question—who made the first telescope? will probably never be conclusively settled. For the invention, in its original form, we are indebted to accident, or to the trials of men who had little knowledge of the principles of the science upon which they were conferring so great a favor. Not a single thing, but a combination of things, the telescope in its earliest forms was a simple combination of certain kinds of convex and concave lenses, known and used as spectacles many years before; and whether the credit of the invention should be given to Metius, Lipperhey, Jansen, Baptista Porta, Galileo, or to others whose names are unknown, it is a most difficult and invidi-

ous task to decide. But interesting though these inquiries may be, it is not my purpose in this dissertation to enter into the discussion of the question as to who was the inventor of the first "optick-tube," or to describe minutely and historically all the several successive changes and improvements which it has undergone in the hands of different philosophers; but rather, to examine the theory of those forms of refracting and reflecting telescopes which have been of more general application.

THE OPTICAL PRINCIPLES INVOLVED IN THE CONSTRUCTION OF THE TELESCOPE.

A telescope, in general, consists of a tube containing a system of glass lenses, or a speculum in combination with such lenses; and is used to render distant objects more clearly visible; (1) by enlarging their apparent angular dimensions, and (2) by introducing into the eye a superior quantity of their light.

Those constructed with glass lenses only, are called dioptric or refracting,

and the others catoptric or reflecting telescopes. In the refracting telescope, rays of light coming from the object are made to converge by a convex lens, and, if not intercepted, form an image at its focus. In the reflecting telescope, the image is formed by the reflection of the rays which impinge upon the concave surface of a speculum.

We will first consider:

I. THE SIMPLE REFRACTING TELESCOPE.

In exhibiting the principles on which the refracting telescope is constructed, we must first explain the formation of the image of an object at the focus of a lens.

When a convex lens is placed before an object, an image of the latter is formed at a certain distance behind or before the refracting surface, whose magnitude is greater or less, according as it is formed farther from, or nearer to the surface. The one particular distance at which the image is distinct, is called the focus. At every other distance it is

hazy and confused. By the use of the telescope the image is produced on the retina of the eye itself, and its office is to prepare the rays of light for forming on the retina an image larger and clearer than would be formed without its help.

In (Fig. 1) two rays proceeding from the top and bottom of the object AB are represented separately. The ray A*a*, passing through the center of the lens O, is unaffected, because the surfaces through which it passes are parallel to each other, and from the property of the lens, all other rays from A, on passing through it, are brought to a focus somewhere on A*a*, depending upon the curvature of the lens. In like manner, all rays from B are brought to a focus at *b*, each point of AB having its corresponding focus in *ab*. The latter is smaller than AB in proportion as *c*O is less than CO; and if we increase the focal length of O till *ab* is twice the distance away, it becomes double its present size. The place of an image depends upon the distance of an object, and when the latter

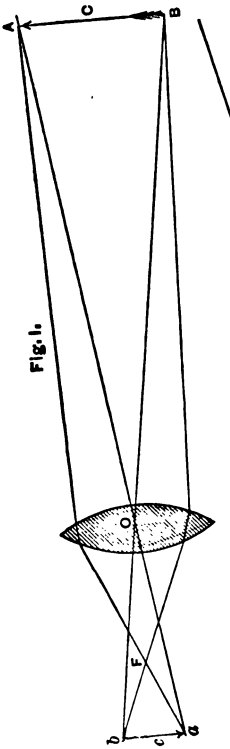


Fig. 1.

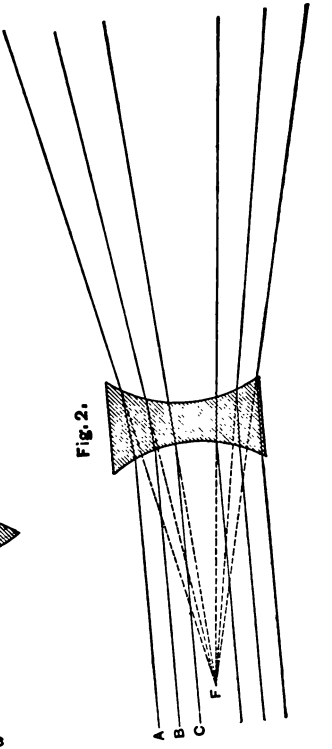


Fig. 2.

is considered at an infinite distance, as is the case with the heavenly bodies, the image is formed at the principal focus of the lens, or the focus of parallel ray.

If rays ABC &c., pass through a concave lens, as in (Fig. 2), they are not brought to a focus, but diverge as if they came from some point F, called the virtual focus.

The first condition which a telescope must fulfill is, that it shall so dispose all rays emanating from any point in an object, that they may emerge from the instrument parallel to each other, in the usual or medium situation of the mechanism.

The second condition is, that the mechanism itself shall be adjustable, so as, by a movement of the parts *inter se*, to convert this parallelism into a slight divergence or convergence, to suit the eyes of near or long-sighted persons.

The third condition is, that the pencils of parallel rays coming into the eye from different points of the object, shall be inclined to each other at greater angles than those actually subtended at the

eye, by the respective intervals between the points themselves. The number expressing this ratio is the measure of the *magnifying power* of the telescope, and the *apparent linear dimensions* of an object being in proportion to its magnifying power, the apparent enlargement of its *superficial area* is as the square of the magnifying power.

The simplest construction of the refracting telescope is that in which the image formed in the focus of a convex lens, or *object-glass*, is viewed through a second lens, or *eye-glass*, so placed as to have the image in its focus for parallel rays incident in the contrary direction, and its axis coincident with that of the first lens.

Three cases arise by applying this principle, which afford telescopes of different characters:

1. The *Galilean telescope*, with double concave eye-glass, showing objects erect.

2. The *Astronomical telescope*, first suggested by Kepler, with double convex eye-glass, showing objects inverted.

3. The *Terrestrial telescope*, suggested by Rheita, with three double convex eye-glasses, showing objects erect.

1. THE GALILEAN TELESCOPE.

In this instrument, the eye-glass PQ (Fig. 3) is placed between the object-glass MN and its focus O′, so that the axes of both glasses are in the same line AO′, and their foci in the same point O′.

(1.) The object OB being supposed infinitely distant, incident parallel rays, as AD, A′D′, A″D″, are first rendered converging towards O′ by MN, and afterwards parallel by PQ. They are also much denser than before their first refraction, and, when received by the eye, paint an image of the object, so much the more vivid, as the density of the pencil of rays is then greater than before it fell upon MN.

(2.) The point B sends forth parallel rays as CD and its two parallels, which are refracted towards some point *b*, and then rendered parallel by PQ. Since this pencil, in emerging from PQ, diver-

ges from that formed by the point O, a greater number of the parts of the object will be seen as the eye is placed nearer to PQ, and as the pupil is more dilated. But since the dilation of the pupil is small, and since it involuntarily contracts in proportion to the quantity of light impinging upon the eye, the field of view is so much the less as the focus of PQ is greater.

(3.) Since the nature of light will not admit of an eye-glass whose focus is diminished beyond a certain limit, and since the focus ought to be longer in proportion to the length of the focus of the object-glass, the field of view will be less the greater the length of the instrument, which inconvenience, together with those above described, render this instrument almost useless for purposes of astronomical observation.

(4.) The pencil of rays *c*, from B, under the axis, meets the eye in the direction *c*F, answering to a point also below the axis; and in the same manner, a ray issuing from any point of the

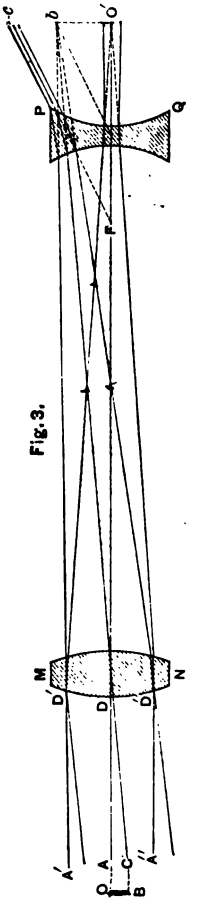


Fig. 3.

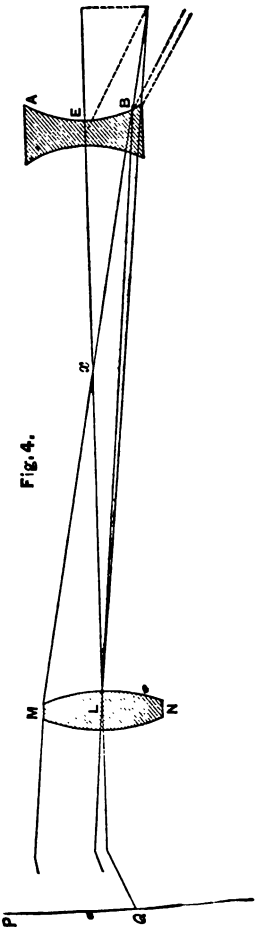


Fig. 4.

object, above the axis, has a similar direction on emerging from the eye-glass. Consequently, objects and their images have like positions with respect to direction, when viewed through a telescope of this construction.

(5.) To determine the field of view, we let MN (Fig. 4) be the diameter of the object-glass, AB that of the pupil of the eye whose center is in the axis of the telescope, and join M and B, the opposite extremities of these diameters, and let MB meet the axis in x, and the image in p. We draw also LB and Lp, and suppose pL and qL to be produced till they meet the object in P and Q. PM is refracted to the pupil in the direction MB, but every other ray in the pencil, as PL, and every ray which comes from a point more distant from the axis, falls below the pupil. Therefore, PQ is half the linear magnitude of the greatest visible area. QP is measured by the angle QLP, or by its equal qLp.

oLo=ELB+BLp, and

$$BLp = LBM - LpM.$$

$$\therefore\ qLp = ELB + LBM - LpM.$$

And 2QP is measured by

$$2ELB + 2LBM - 2LpM.$$

That is, the linear magnitude of the field of view is measured by the angle which the diameter of the pupil subtends at the center of the object-glass, increased by the difference between the angles which the diameter of the object-glass subtends at the pupil and at the image.

2. THE "ASTRONOMICAL" TELESCOPE.

This instrument, represented in (Fig. 5), differs from the Galilean, in having a convex instead of a concave eye-lens, which is so placed with regard to the object-glass that their foci coincide in the axis of the telescope between the two glasses, instead of being beyond the eye-glass as in the Galilean telescope. PQ is the eye-glass, MN the object-glass, KD the axis, and *o* the common focus.

(1.) The rays AD, A′D′, A″D″ from O in the object OB, infinitely distant,

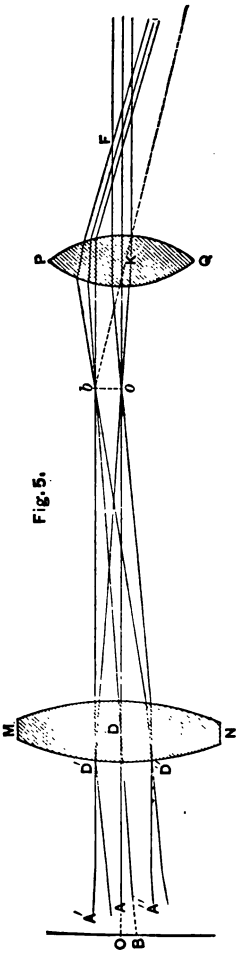


Fig. 5.

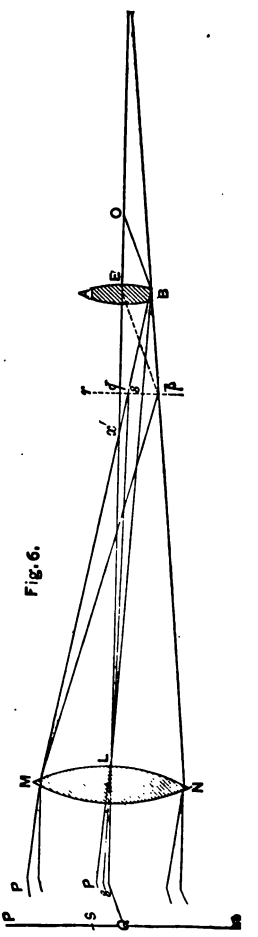


Fig. 6.

are refracted to the focus *o* where they form an image of O.

(2.) This image *o* is considered as an object placed in the focus PQ, and rays diverging from *o*, and falling on PQ emerge parallel to each other, and are so much the more dense as the focal length of PQ is less than that of MN. They therefore paint on the retina a new image of O, which is so much the more vivid, as the surface of MN is greater—that is, as it admits a greater quantity of light.

(3.) Rays from B form in *b*, an image of this point, and falling afterwards on PQ, emerge parallel and more inclined to AF as the curvature of PQ is greater; so that the axis of the pencil which they form, cuts the common axis of the two lenses in F, the focus of PQ. Consequently, to see all of *ob* at the same time, the eye must be placed at F, the common intersection of all rays emitted from each point of *ob*, or of OB.

(4.) *b*, the image of B, is refracted to the eye in the direction PF, and has a

different direction from that in which it is emitted from B; and the ray which renders visible a point above the axis reaches the eye as if it proceeded from below the axis; and thus the entire image is reversed.

(5.) To find the field of view, we let MN (Fig. 6) be the diameter of the object-glass, AB that of the eye-glass, and draw NB, letting it cut the image *pqr* in *p*. We draw also *p*L, and conceive *p*L and EL to be produced until they meet the object in P and Q; and draw *p*E and NP, and also BO parallel to *p*E. Then the eye at O receives the ray NBO, which comes from a point in the object at the greatest visible distance from the axis of the telescope. For rays from any point above P, converge to a point below *p*, and fall below AB; consequently P is the exteme visible point in the object, and QP is half the linear magnitude of the visible area.

(6.) To find the *brightest area*, we draw MB cutting *pqr* in *s*, and the axis LE in *x'*, and draw L*s*, and conceive it

produced till it meet the object in S. Then, (*a*) if x'E be greater than qE, all rays from S falling upon MN, are refracted to AB; for, SM is refracted in the direction MsB, and any other ray of the pencil, as SL, crosses MB at s, and falls somewhere between A and B. In like manner, rays from any point between S and Q, are refracted to AB. (*b*) If x' and q coincide, the brightness of the field increases to the center. (*c*) If q *fall between* L and x', all the rays belonging to any one pencil incident upon MN, are not received by AB.

3. THE TERRESTRIAL TELESCOPE.

The nature of this construction is easily comprehended by reference to (Fig. 7). The four lenses have one common axis A f. and each contiguous two are so situated that their foci coincide. If OB be an infinitely distant object, the parallel rays from O, in the axis produced, from an image in the focus o, whence, falling on, PQ they emerge parallel to each other and to the axis. Falling upon RS,

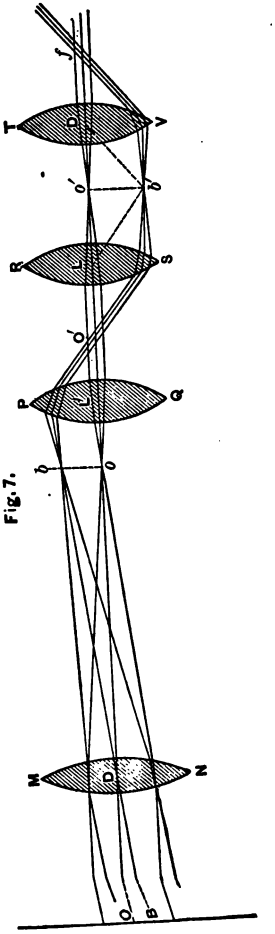


Fig. 7.

they are refracted to the focus o', where a second image is formed; and then diverging, and falling on TV, they are refracted to the eye in directions parallel to the axis. In like manner, rays from B form in b an image of that point, whence, falling in PQ they are rendered parallel to each other, but oblique to the axis till they meet RS, by which they refracted to the second focus b'; whence, falling on TV, they are again rendered parallel to each other, but so inclined to the axis as to meet it again with all the other rays in the focus f, where the eye is placed to receive the final impression, which is that of an image corresponding, as to its direction, with the object itself. For the ray b'Vf, which carries the image of the point B, has a similar direction with respect to the axis, as the ray proceeding immediately from B.

As the properties of this instrument are analogous to those of the astronomical telescope, it is unnecessary to enter into further discussion of the principles of its construction.

II. THE REFLECTING TELESCOPE.

Having considered the principles on which the simple refracting telescope is constructed, we will next explain the manner in which the properties of the reflection of light are utilized for astronomical observation by the reflecting telescope.

An image may be formed by reflection from a polished surface, wrought into a regular convexity, on the same principles of the divergence and convergence of the reflected rays, as by refraction through polished transparent surfaces.

If rays of light, falling upon a concave mirror, diverge from a point beyond the center of curvature, they will converge after reflection, to a point between the principal focus, or focus for parallel rays, and the center of curvature. This point is called the conjugate focus.

If light radiates from L (Fig. 8), it is reflected to *l*; if it radiates from *l*, it meets at L. If the radius of the mirror and the distance of one focus from

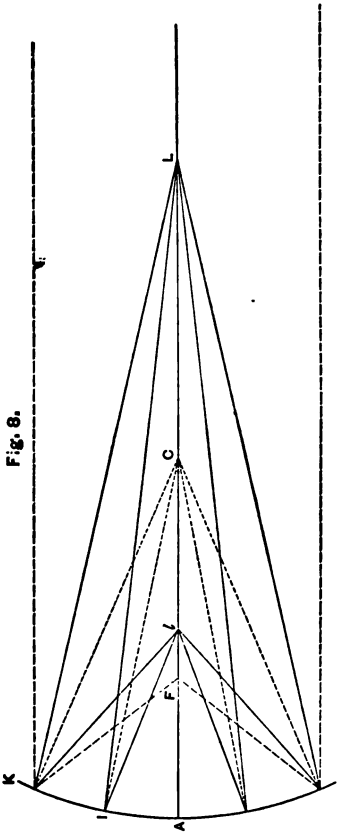


Fig. 8.

are given, the distance of its conjugate focus may be determined. As the angle LKl is bisected by the radius KC, we have LK : lK :: CL : lC—that is, when KA is considered very small, LA : lA :: CL : lC, or, letting r=radius, LA : lA :: LA—r : r—lA. Hence, $\mathrm{LA}=\frac{r \cdot l\mathrm{A}}{2l\mathrm{A}-r}$, and $l\mathrm{A}=\frac{r \cdot \mathrm{LA}}{2\mathrm{LA}-r}$. If the luminous point is at C, all the rays will be "reflected back" to the same point, and while the radiant point moves from C to infinity, the conjugate focus moves from C to F,—the principal focus.

Although there are many cases arising from the reflection of light at curved surfaces, due to position of mirror and direction of incident rays, it will be sufficient for our purpose to consider those particular cases of reflection which are involved in the construction of the various forms of the reflecting telescope.

By an examination of (Fig. 9), the formation of an image by a concave mirror is easily understood. The rays

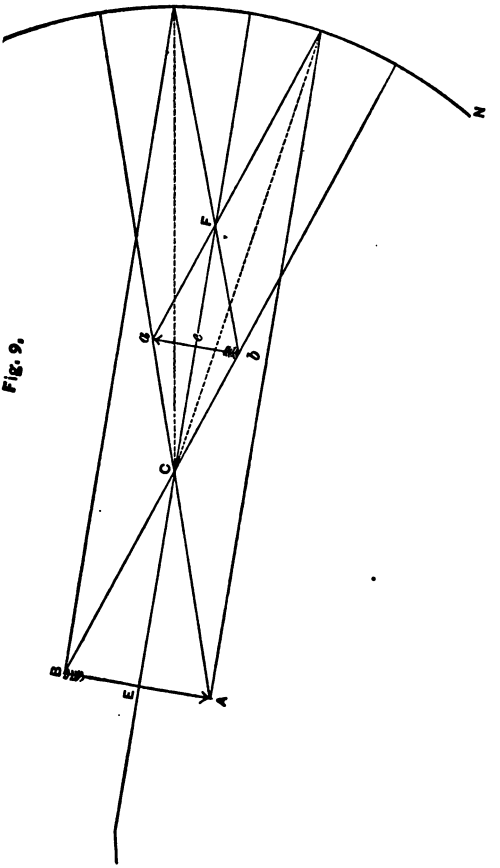


Fig. 9.

AC*a* and BC*b* from the object AB passing through the center of curvature C, fall perpendicularly on the surface MN, and are "reflected back" on themselves, so that the focus of the point A is somewhere on A*a*, and that of B on B*b*. By drawing another ray from A, we find it reflected to *a*, which is the focus of A; and by drawing another ray from B, we find it reflected to *b*, the focus of B. Since A*a* and B*b* cross at C, *ab* is smaller than AB, as *e*C is smaller than EC. When the object is a heavenly body, it is at a practically infinite distance, and the rays are parallel, and the image found half-way between the mirror and its center of curvature.

In regard to the convex mirror, the only case which happens in the reflecting telescope is that of converging rays incident upon a surface of such convexity as to render them less convergent.

In (Fig. 10) we consider the light, after having been reflected from some converging surface, to proceed to the convex mirror along the lines GA and HB,

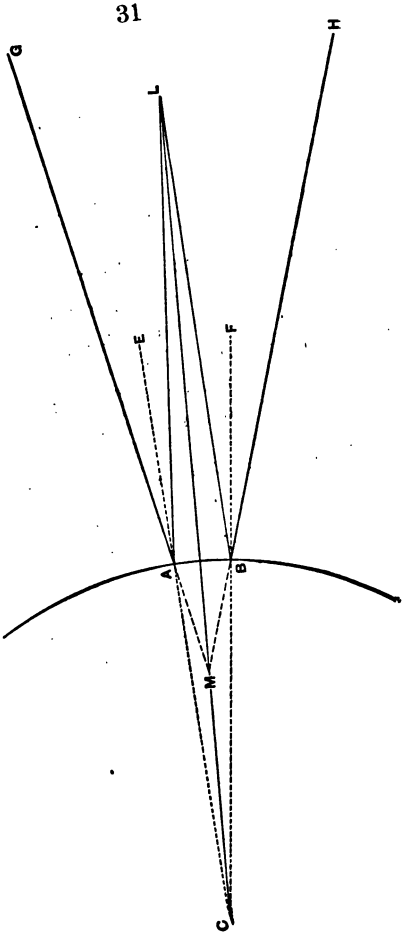


Fig. 10.

towards some point M. These rays, after reflection converge to L, and come to a focus in front of the mirror, at a point further in front than its center C is be hind it, so that they have been rendered less convergent.

As the image formed by the concave speculum of a telescope is on the same side as the object, some arrangement is necessary to prevent the observer's head obstructing the passage of light to the speculum, and hence we have

1. FOUR DIFFERENT FORMS OF THE REFLECTING TELESCOPE.

(1). *The Herschelian Telescope*.—In this instrument the speculum is so tilted as to bring the image to one side of the tube. The concave reflector AD (Fig. 11) is fixed at the bottom of the tube MN M′N′, and tipped so that its axis GC bisects the angle ECc, between the axis of the tube and a line Cc from its center to the edge of the opening of the tube. Parallel rays, falling on AD, are reflected to the side of the tube, where the

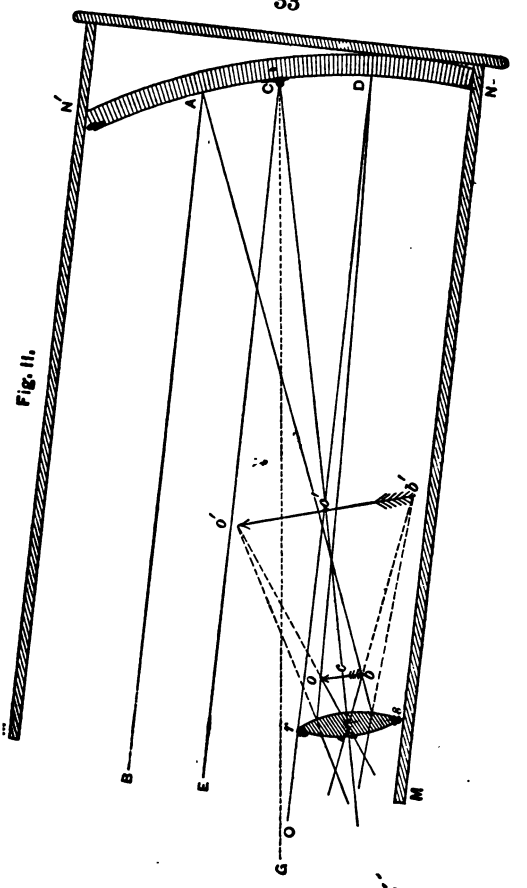
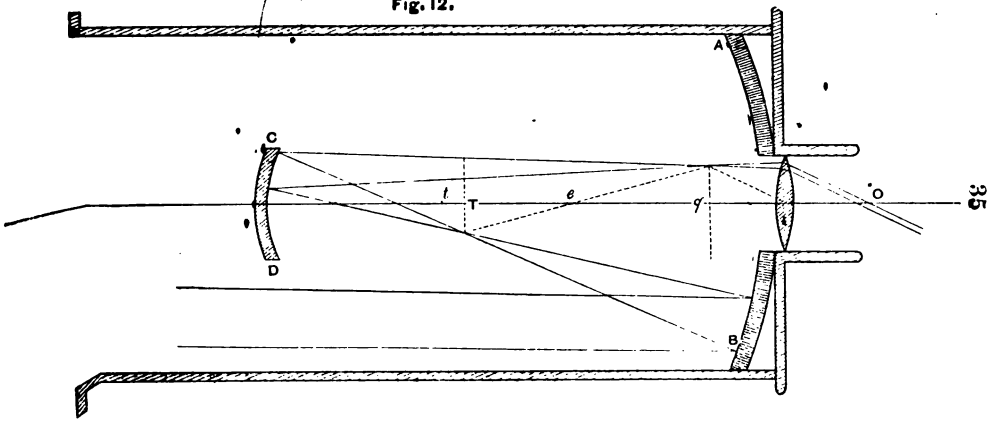


Fig. II.

image is formed, and where the eye-glas is placed to magnify it. The image o is represented as being magnified by single convex lens *rs*. As it falls be tween *rs* and its principal focus, a sec ond, and enlarged, image is formed at *o'b* While the Herschelian has the brightes image of all the reflecting telescope with a given aperture, and possesses th advantage—so thoroughly appreciate by those in the habit of observing fo many consecutive hours—of allowing th observer always to look downward, it disadvantages are still many. It canno produce the finest definition, because th reflecting surface cannot bring the ray to an exact focus when they are throwi so far to one side of the axis of the tube and the injury to definition, on this ac count, is so great that the "front view" plan has been almost entirely aban doned.

(2). *The Gregorian Telescope.*—The general principle of this construction i shown in (Fig. 12). AB is the specu lum. A little beyond the image T

Fig. 12.



which is formed in the axis OT, is a small concave mirror CD. T is, with regard to CD, as an object placed between its focus *t*, and its center *e*; and CD forms a second image *q*, more or less distant from *e* as T is nearer to, or more remote from *t*. By moving CD nearer to, or further from T, *q* may be carried to any distance. The latter is commonly brought a little in front of AB, in which is an aperture, through which, by means of a proper eye-glass, *q* is viewed. The image appears erect, being reversed with regard to T, which is itself reversed with respect to the object.

(3). *The Cassegrainian Telescope.*—In this construction the smaller reflector CD (Fig. 13) is convex, and so placed that the image T falls between CD and its principal focus *t*. If CD be removed, and the axis GcE directed to Q in the object PQ, an inverted image TV, terminated by the lines QET and PEV, is formed in the principal focus of AB. But if CB be replaced the rays are intercepted by it before they reach T, and

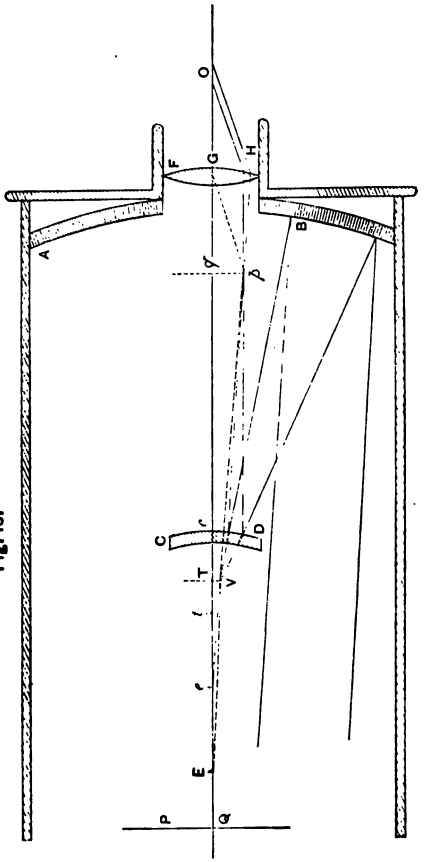


Fig. 13.

since TV falls between the surface CD, and its principal focus *t*, an erect image *qp* of TV is formed, and is terminated by the lines *e*T*q* and *e*V*p*. This image is viewed through the lens FGH, whose focal length is G*q*.

Objects appear inverted, for *pq*, which is erect with respect to TV, or inverted with respect to PQ, is in or near the principal focus of FGH; the image upon the retina is, therefore, erect, and consequently the object will appear inverted.

(4). *The Newtonian Telescope.* — A representation of this telescope is given in (Fig. 14), in which DAD is a concave speculum, and IH a small plane mirror, inclined 45° to the axis of DAD. The image of OB, which would have been formed at *o'b'*, is caused by III to be formed in *ob*. The latter is observed through an opening made in the side of the tube directly opposite III, and furnished with an eye-glass *cd*.

If we let PQ (Fig. 15) be the object, *pq* its image, *nm* the image formed by the plane surface IcII, and *klr* a convex

eye-glass, whose focal length is *ln;* then *mn*, equal to *pq*, and corresponding to QP, is seen through *klr*, under the angle *mln*; and QP is seen, with the naked eye placed at the center E, under the angle *q*E*p*. Since these angles have equal subtenses—*mn* and *qp*—they are to each other inversely as *ln* and E*q*, and, consequently, the angle which the object subtends at the center of the eye, when viewed with the telescope, is to the angle when viewed with the naked eye, as *q* is to *ln*—that E is as the focal length of the speculum is to that of the eye-glass. The fraction $\frac{Eq}{ln}$ is, therefore, the measure of the *magnifying power* of this telescope.

Having explained the optical principles underlying the construction of the most common forms of the reflecting telescope, we will next show what difficulties have to be overcome, in order to make large reflectors perfect.

Although the reflector possesses an enormous advantage over the refractor,

in its inherent immunity from chromatic aberration, there is something else which quite lowers its position with regard to the latter, and that is,

2. SPHERICAL ABERRATION BY REFLECTION.

That all light falling in parallel lines on a concave spherical surface is reflected to a focus, is true only in a general sense. In (Fig. 16) MI is a section of a speculum, whose center of curvature is L, and DC, EG and HI, incident parallel rays. To find the focus of EG we draw LG, and make the angle FGL equal to EGL. But in repeating the process for HI it is reflected to K, and the further the rays from DC, the further from F is the light reflected. The edges of MI must, therefore, be thrown back to ACB, which makes its margin a part of a less concave speculum, and throws its focus further from itself, to F instead of to K. It is evident that this curve, which will throw all the parallel rays to one point, is the parabola; and the speculum, especial-

ly when of large diameter, is of no use without an *approximate* parabolic curve.

It is in the *polishing* of specula that the curve is altered from the spherical to the parabolic form, and it is here that the finest niceties of manipulation come into play, and the utmost skill and patience are required. That it is extremely difficult to give the parabolic figure, may be gathered from Sir John Herschel's statement, that in the case of a speculum 48 inches in diameter, and 40 feet in focal length, the distance between the spherical and parabolic surfaces at its edges was $\frac{1}{21333}$ of an inch.

In regard to the form of specula, it may be stated generally, that that is a good form which gives a good image; and that the geometrical distinctions between the sphere and parabola become mere theoretical abstractions in the figuring and polishing of specula, there being no practical mode of ascertaining, by any system of measurements on a scale, *what* form the surface has, apart from the optical effect on the rays of light.

III. THE COMPOUND REFRACTING, OR MODERN APLANATIC AND ACHROMATIC TELESCOPE.

In discussing the simple refracting telescope, it was assumed that spherical lenses bring rays of light, issuing from a point, to a focus without *dispersion*. But where the greatest accuracy is required, it becomes necessary to consider the imperfections of spherical lenses, and to discuss the subjects of *spherical* and *chromatic aberrations*, upon a perfect understanding of which the construction of the modern refractor depends.

1. THE "OBJECTIVE."

(1). *Spherical Aberration by Refraction.*—If the diameter of the lens VW (Fig. 17) is large in proportion to its radius of curvature, parallel rays are not brought to an accurate focus, but while the central rays cross the axis at F, the extreme rays intersect it at G, and intermediate rays at points between F and G. To estimate the amount of spherical aberra-

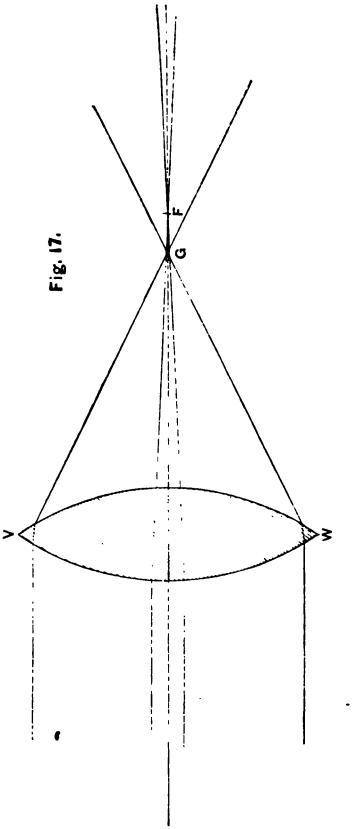


Fig. 17.

tion in any case,* we calculate the course of a ray falling upon the border of the lens. AC (Fig. 18) is a section of the curved refracting surface, and QCq its axis. The refractive index is n. The distance QC, of the radiant point, is given, and also CD and AD co-ordinates of the point A. Hence, the normal AE and sub-normal DE may be found. Aq is the refracted ray required, cutting QCq in q.

sin incidence : sin AEC : : QE : QA.

sin E : sin refraction : : qA : qE.

$\therefore$ sin incidence : sin refraction

$$: : n : 1 : : \frac{q\mathrm{A}}{q\mathrm{E}} : \frac{\mathrm{QA}}{\mathrm{QE}},$$

$$\therefore \quad \frac{q\mathrm{A}}{q\mathrm{E}} = \frac{n \,.\, \mathrm{QA}}{\mathrm{QE}} = c \text{ (a known quantity).}$$

$\overline{q\mathrm{A}}^2 = c^2 . \overline{q\mathrm{E}}^2$, that is,

$$\overline{q\mathrm{E}}^2 + \overline{\mathrm{EA}}^2 + 2q\mathrm{E} \,.\, \mathrm{ED} = c^2 \,.\, \overline{q\mathrm{E}}^2,$$

$$\therefore \quad (c^2 - 1)\overline{q\mathrm{E}}^2 - 2\mathrm{ED} \,.\, q\mathrm{E} = \overline{\mathrm{EA}}^2.$$

$$\therefore \quad \overline{q\mathrm{E}}^2 - \frac{2\mathrm{ED}}{c^2 - 1} \,.\, q\mathrm{E} = \frac{\overline{\mathrm{EA}}^2}{c^2 - 1}$$

* *Microscopical Journal*, Vol. VIII., p. 21.

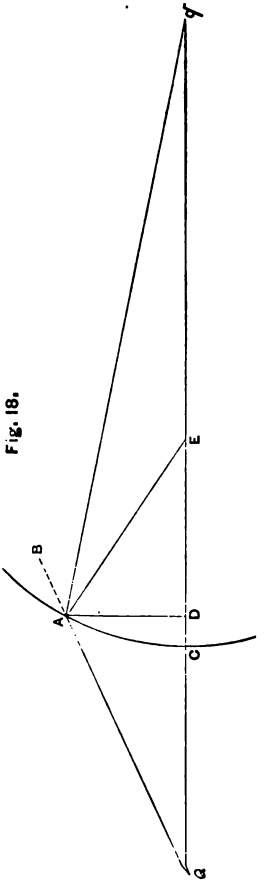


Fig. 18.

$$\therefore \left\{ qE - \frac{ED}{c^2-1} \right\}^2 = \frac{\overline{ED}^2}{(c^2-1)^2} + \frac{(c^2-1)\overline{EA}^2}{(c^2-1)^2}.$$

$$\therefore qE = \frac{1}{c^2-1} \cdot \left\{ ED \pm \sqrt{\overline{ED}^2 + (c^2-1)\overline{EA}^2} \right\}.$$

From this formula the value of qE for any surface may be calculated. For lens of small aperture, the aberration is in proportion to the square of the angular aperture of the lens ; but for lenses of larger aperture, the aberration increases more rapidly.*

If n equals the index of refraction, r the radius of the anterior surface, and R that of the posterior surface of a lens, then, for parallel rays, the form for least aberration is expressed by the equation, $-\frac{r}{R} = \frac{4+n-2n^2}{2n^2+n}$. If $n=1.5$, the form for least aberration is a lens whose sur-

* If the length of the principal focus be taken as unity, the longitudinal aberration FG (Fig. 17) for lenses of different angular aperture will be as follows:

For 15°	the aberration will be	.....	0.025.
" 22°	"	"	0.062.
" 30°	"	"	0.150.
" 45°	"	"	0.375.

faces have their radii in the proportion of 1 to 6, with the side of deeper curvature towards the object—the longitudinal aberration then being only 1.07 times the thickness of the lens.*

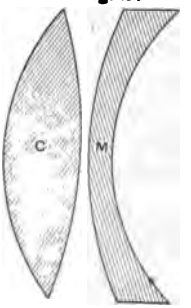
No expedient has been discovered by which the spherical aberration of single lenses can be rendered less than 1.07 of their thickness; but if, instead of a double-convex lens, two plano-convex lenses be used, so placed that their convexities shall be turned towards each other, their combined aberration will be only 0.248, or about $\frac{1}{4}$ of their thickness, provided that the focal length of one be 2.3 times that of the other; and the spherical aberration may be wholly effaced by the combination of a double-convex lens C (Fig. 19) with a meniscus M, having suitable curvatures. In this

* Supposing the lens of least spherical aberration to have its aberration equal to 1, that of the other lenses will be as follows:

Best form	1.000.
Double convex or concave, with equal curvature	1.567.
Plano-convex, with convex side towards object	1.081.
Plano-convex with plane side towards object	4.206.
Plano-concave same as plano-convex.	

case the convex side of M must b
turned towards the object.*

Fig. 19.



Although it is hardly possible, in prac
tice, to efface altogether the effects c

*C.	1st Combination.	2nd Combination
Focal length	10.000	10.000
Rad. of outer surface	5 833	5.833
" " inner "	35.000	35.000
M.		
Focal length	17.829	5.497
Rad. of outer surface	3.688	2.054
" " inner "	6.291	8.128
Focal length of combinations	6.407	3.474

spherical aberration, they have been so considerably diminished by the adaptation of the curvatures of lenticular surfaces, that in well-constructed telescopes they may be regarded as entirely removed for all practical purposes. The work has been accomplished by giving to the two sides of the lenses different curvatures, so adapted that the aberration produced by one shall be more or less counteracted by the aberration produced by the other.

(2.) *Chromatic aberration.* — White light, when refracted by a lens of any single transparent substance, like glass, is acted upon as by a prism, and dispersed into all the colors of the solar spectrum. This effect is shown in (Fig. 20), where V is the focus of the violet rays, which are most refracted, and R is the focus of the red rays, which are least refracted. A violet image is formed at V, and a red image at R, and the space VR is occupied by images of intermediate colors. An image of a point formed at V is violet, but surrounded by fringes of all the colors of

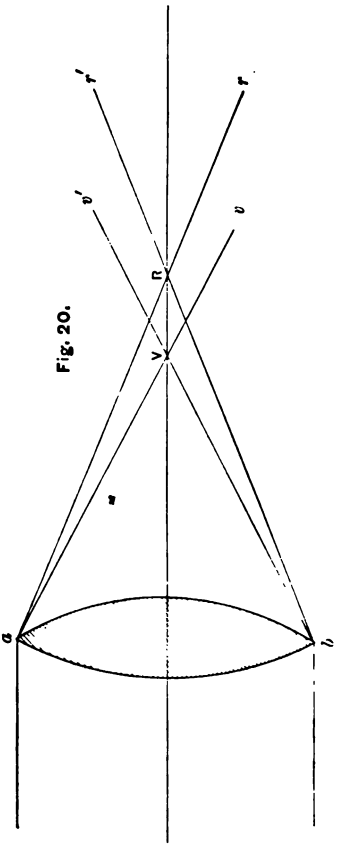


Fig. 20.

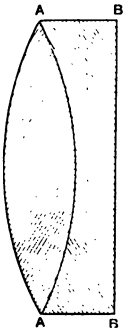
the spectrum, the outer border being red.

To refract light, and still keep the colors united, it is necessary, after the rays are refracted, and thus separated, to use a substance of greater dispersive power, which brings the rays together again by refracting them only a part of the distance back to their original direction.

The problem is: can we make two lenses of different kinds of glass, with equal dispersive, but unequal refractive, powers? The researches of Euler and Dolland answer in the affirmative, by showing that the dispersive power of dense flint glass is about double that of crown glass, while the refractive power is nearly the same. Hence, a double-convex lens of crown glass AA (Fig. 21) is united with a plano-convex lens of flint glass BB, having a focus about double that of AA. BB corrects the chromatic aberration of AA, leaving about $\frac{1}{2}$ of the refractive power of AA as the effective refracting power of the

compound lens. No exact rule respecting the ratio of the curvature can be given, because the refractive powers of different specimens of glass differ, and the proper ratio in each case is found by

Fig. 21.



-rial. Having found it, the two lenses have equal aberrations, but in opposite directions, while AA refracting more powerfully than BB, the rays are brought to a focus at a distance a little ›re than double the focal distance of
A

Having explained the general principles upon which achromatic lenses are produced, it will be satisfactory in a question of such importance to supply the mathematical details of its solution. The problem is: to find what form must be given to two lenses of different refractive powers, to render the focal length of the compound lens, for light of any one refrangibility, equal to that for light of any other refrangibility. Let F' and F'' be the focal lengths of the two lenses for light, of which the indices of refraction are n' and n'' for the media composing the lenses respectfully. Let f' and f'' be their focal lengths for light of which the indices of refraction are m' and m''. Let F be the focal length of the compound lens. The converging power of the compound lens, on each kind of light, is equal to the sum of the converging powers of the two lenses, separately, on the same kind of light. The *converging power* of the compound lens, therefore, on the light whose indices

of refraction are n' and n'', is $\frac{1}{F'}+\frac{1}{F''}$, and its converging power on the light whose indices of refraction are m' and m'', is $\frac{1}{f'}+\frac{1}{f''}$. But since these two converging powers must be rendered equal, we have, $\frac{1}{F'}+\frac{1}{F''}=\frac{1}{f'}+\frac{1}{f''}$. We have, then, to assign such magnitudes to the radii of the surfaces of the lenses as will fulfill this condition. Let R_1 and R_2 be the radii of the surfaces of the first, and r_1 and r_2 those of the surfaces of the second lens. When F equals the focus of parallel rays, r and r', the radii of the surfaces, and n the index of refraction of any lens, we have, by a formula of optics :

$$F=\frac{rr'}{(n-1)(r-r')}.$$

By this formula:

$$\frac{1}{F'}=\frac{(n'-1)(R_1-R_2)}{R_1R_2},\ \frac{1}{F''}=\frac{(rc''-1)(r_1-r_2)}{r_1r_2};$$

$$\frac{1}{f'}=\frac{(m-1)(R_1-R_2)}{R_1R_2},\ \frac{1}{f''}=\frac{(m''-1)(r_1-r_2)}{r_1r_2}.$$

But since

$$\frac{1}{F'}+\frac{1}{F''}=\frac{1}{f'}+\frac{1}{f''},$$

we have,

$$\frac{1}{F'}-\frac{1}{f'}=\frac{1}{f''}-\frac{1}{F''}.$$

Therefore,

$$\frac{(n'-m')(R_1-R_2)}{R_1R_2}=-\frac{(n''-m'')(r_1-r_2)}{r_1r_2},$$

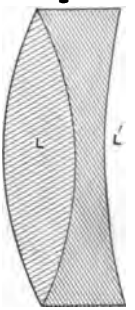
and consequently,

$$\frac{n'-m'}{n''-m''}=-\frac{(r_1-r_2)R_1R_2}{(R_1-R_2)r_1r_2}.$$

(n') and $(n''-m'')$ are the difference between the indices of the two lights having different refrangibilities, or the *dispersive powers* of the media composing the lenses for each of the two lights. If, then, the radii of the two lenses be so selected as to render $\frac{(r_1-r_2)-R_1R_2}{(R_1-R_2)r_1r_2}$ equal to the ratio of the dispersive powers of the materials of the two lenses for the two kinds of light, the latter are brought to the same focus by the compound lens.

Suppose the first a double-convex lens L (Fig. 22), with equal radii, and the second a double-concave lens L′, the surface of which, in contact with the first, has the same curvature with it, and,

Fig. 22.



consequently, the same radius. Observing that when the convexities are turned in contrary directions, the radii have contrary signs $\frac{n'-m'}{n''-m''} = -\frac{(r_1-r_2)R_1R_2}{(R_1-R_2)r_1r_2}$ is now reduced to $\frac{n'-m'}{n''-m''} = \frac{r_2-R_1}{2r_2}$

Let us suppose that the double-convex lens is composed of crown glass, for which $n'=1.546566$, and $m'=1.525832$; and the double-concave of flint glass, for which $n''=1.671062$ and $m''=.1627749$. We then have $\frac{n'-m'}{n''-m''}=\frac{.020734}{.043313}=\frac{r_2-R_1}{2r_2}$. Hence $r_2=23.47\times R_1$. The radius of the second surface of L′ must in this case, therefore, be 23.47 times the radius of L.

Some of the earlier achromatic objectives were made of three lenses, as in (Fig. 23), a double concave lens of flint glass being fitted between two double convex lenses of crown glass. In June, 1860, Professor Steinheil communicated to the Royal Academy of Sciences at Munich, a notice of an object-glass of the form shown in (Fig. 24), executed according to the system of curves proposed by Gauss. The curves in this combination bear a considerable resemblance to the systems designed with express reference to the correction of spherical

aberration, and for a long time object-glasses of this form were claimed by the most competent judges to exhibit a more complete achromatism, and in other re-

Fig. 23.

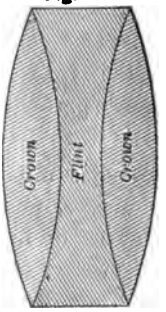
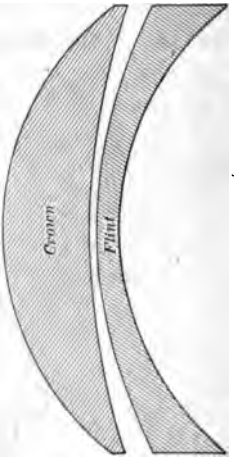


Fig. 24.



spects more perfect definition, than was found with object-glasses of other forms.*

* Paper published by G. P. Bond in 1863 on "The New Form of the Achromatic Object-Glass introduced by Steinheil." Also, "Proceedings of the American Academy of Arts and Sciences." Vol. vi.

The problem presented to the mathematician, as to what shall be the form and disposition of the surfaces of two or more lenses composed of materials of different dispersive powers, which shall most effectually destroy the aberration of color and figure, is an indeterminate one; so that, for every lens of crown glass of positive focus, whatever the radii of its surfaces may be, a lens of flint glass can be constructed which will form, when united with it, an achromatic and aplanatic object-glass. This allows a great range in the choice of curves, and a variety of conditions have been proposed by different authorities for determining the selection. The theory of telescope objectives is at this time being discussed by many able mathematicians, among whom, in our own country, are Professors Newcomb and Harkness, of Washington, and Professor Chas. Hastings, of the Johns Hopkins University. In regard to the form of objectives, Messrs. Alvan Clark and Sons, of Cambridgeport, Mass., whose reputation as

telescope makers is known throughout the world, in a letter to me, dated March 10, 1879, say: "Many forms may be used, but from our experience we have found that to *make the crown glass lens of equal curvature, and the flint glass lens nearly flat on the side next the eye*, is the most convenient, and *gives as good results as any other form;* of course, the curves must differ with different glass used; but the difference will be small." This is the form shown in (Fig. 21). If the dispersive power of the flint were just double that of the crown, the outer face of the former would have to be a plane surface to produce achromatism, but this is not generally the case. As no two specimens of glass made at different meltings have exactly the same refractive and dispersive powers, the optician must find the ratio of the dispersion of the two glasses, and then give the outer face of the flint such a degree of curvature as to neutralize the dispersion of the crown. Usually, this face will have to be slightly concave.

(3.) *Secondary Spectrum.*—The image formed at the focus of a so-called achromatic lens is not absolutely colorless. A difficulty arises from the fact that flint glass, as compared with crown, disperses the violet end of the spectrum more than the red end. If R, G, and V, (Fig. 25), are the centers of the red, green and violet in the spectrum given by a prism of the glass of which one lens is made, and R′, G′, and V′, are those of the other; and if the lenses are placed so as to counteract each other, and are of such curves that the red and violet are combined, the green remains slightly outstanding. If the second prism disperses the violet as much as the first one does, when they are reversed they exactly compensate red and violet. But the second acts more strongly than the first on the green, which is overcompensated; and if we weaken the second prism, so that the green and red are corrected, then the violet will be slightly outstanding. The defect is hardly noticeable in small telescopes, but in the

immense refractors of two feet aperture, or upwards, this secondary aberration

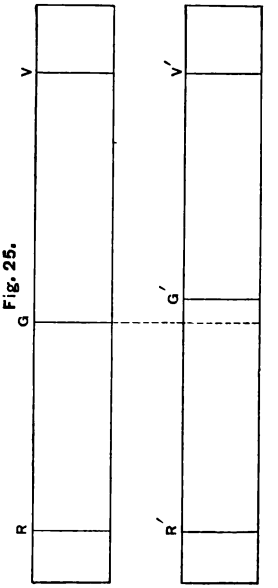


Fig. 25.

constitutes the most serious optical defect—a defect which, arising from the properties of glass itself, no art can dim-

inish. It has been suggested that this difficulty may be lessened by increasing the length of the instrument. But in doing this with glasses of such large size, engineering difficulties will be encountered which soon become insurmountable, and it is the opinion of many opticians and astronomers that "the limit of optical power for such instruments *has been very nearly attained.*"

(4.) DOUBLE REFLECTION.

When the curvatures of the inner surfaces of the glasses of an achromatic lens are such that they exactly fit each other, they are frequently joined together with a transparent balsam, so as to diminish the loss of light in passing through the lens. Whenever light falls upon transparent glass, between 3 and 4 per cent. of it is "reflected back," and when, after passing through, it leaves again, about the same amount is "reflected back" into the glass. Consequently, about 7 per cent. of the light is lost in passing through each lens. By

joining them with castor-oil or balsar
the reflection from the second surface
the flint, and the first surface of tl
crown is very much diminished, and tl
loss of about 6 per cent. of the light
avoided. In case there is no balsan
the inconvenience of *double reflectio*
arises. Some of the light "reflecte
back" from the second surface of th
flint, is again reflected from the firs
surface of the crown, and sent down t
the focus of the telescope with th
direct rays. If one of the lenses be di
placed in the slightest degree, the r
flected rays will come to a differen
focus than the direct ones, and ever
bright star, for instance, which is viewe
with the instrument, will seem to have
small companion star along-side of it.

2. THE EYE-PIECE.

We have thus far discussed the optic
principles which are applied in the co
struction of refracting and reflectin
telescopes, consisting of an object-gla
or speculum and an eye-piece of th

simplest form, viz.: a single double-convex lens. We will now go into detail somewhat on the subject of eye-pieces, and explain some of the different kinds.

Every ordinary lens possesses the disadvantages of both chromatic and spherical aberration, which have been discussed in connection with the objective. But the eye-piece is not corrected for these errors, in the same way that the objective is. In the case of the former, the errors are corrected by using two lenses of such focal lengths, or at such a distance apart, that each counteracts the defects of the other. We do not use two kinds of glass as in the case of the objective, but so arrange the lenses, that the colored rays produced by the first lens shall fall at different angles of incidence on the second, and thus become recombined.

(1.) THE HUYGHENIAN EYE-PIECE.

This eye-piece consists of two plano-convex lenses A and B (Fig. 26), with their convexities turned towards the

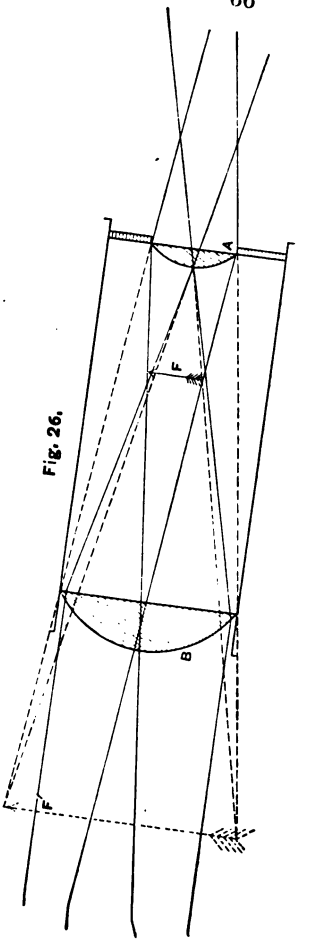


Fig. 26.

object-glass, and having their focal lengths in the proportion of 3 to 1. The strongest lens, A, is next the eye, and B is placed inside the focus of the object-glass and brings the image to a focus at F, about halfway between A and B. This image is then viewed by A, and a magnified image of it is seen at F′. To show how this combination is achromatic, let us consider the path of a ray falling on the lens near B (Fig. 27). It is there refracted, but as the violet rays are refracted more than the red, there are two rays produced, *r* and *v*, giving a colored edge to the image. But when this image is viewed by A, it no longer appears colored, for *v*, falling nearer the axis of A, is less bent than *r*, and they are rendered nearly parallel and appear to proceed from the point F′, where the image appears without color. The focal length of B is three times that of A, and they are placed at a distance of half their joint focal length apart.

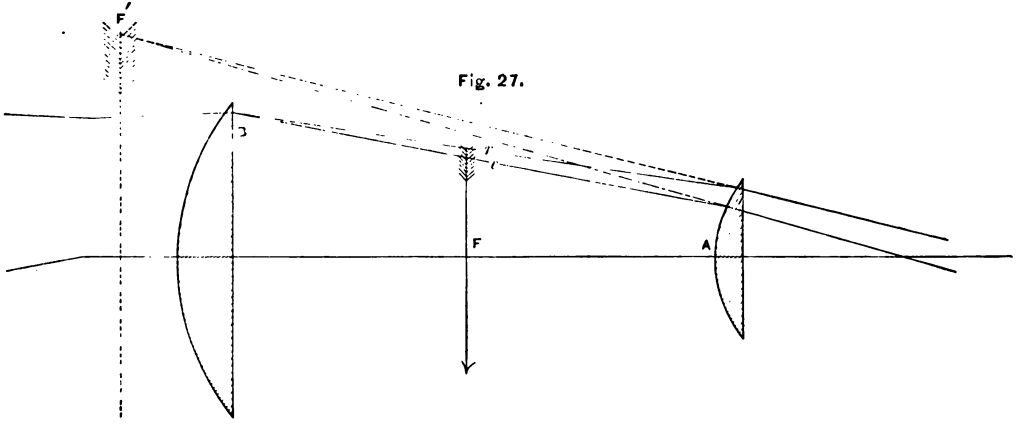


Fig. 27.

(2.) THE RAMSDEN EYE-PIECE.

The Ramsden eye-piece consists of two plano-convex lenses, A and B (Fig. 28), of the same focus, placed at a distance of two-thirds the focal length of either apart. They are both on the eye side of the focus of the object-glass, and act together to render the rays parallel, and give a magnified virtual image of FF'. This eye-piece is not strictly achromatic, but suffers least of all from spherical aberration, and has the advantage of being placed behind the focus of the object-glass, which makes it superior to others in instruments of precision.

(3.) THE ERECTING, OR DAY EYE-PIECE.

The eye-pieces, which we have described, give an inverted image of the object, that is, they do not right again the inverted image formed by the object-glass. Fig. 29 is a diagram of an erecting eye-piece due to Rheita, and called by his name. It is merely a second application of the same means

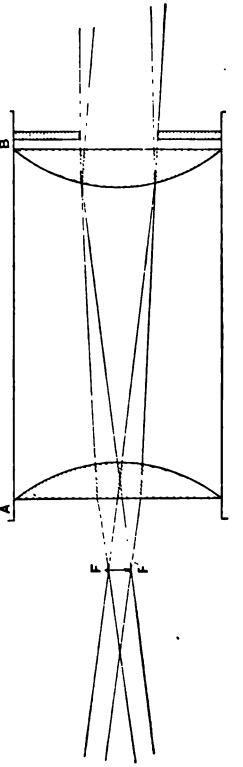


Fig. 28.

that first inverts the object AB, viz., a second small telescope. Dolland substituted an Huyghenian eye-piece for the eye-lens H, and so made what is called "Dolland's Four Glass Eye-piece."

Other forms of eye-pieces might be mentioned, as the *Pancratic Eye-piece*, the different forms of *Solar Eye-pieces*, etc., but the various forms, which have been described, are sufficient to illustrate the general principles involved in the construction of those most commonly used for astronomical investigations.

IV. COMPARISON OF REFRACTING AND REFLECTING TELESCOPES.

A word or two remains to be said in regard to the relative advantages and disadvantages of the two classes of instruments. The question arises, To which class will the great telescope of the future probably belong? Will it be a refractor or a reflector? In treating of the question of the future of the telescope, many authors have encroached

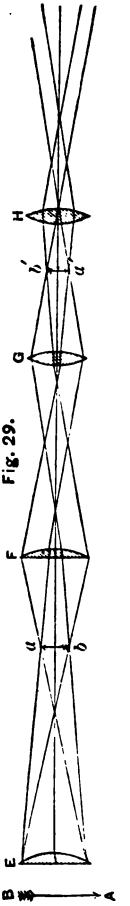


Fig. 29.

upon the domain of opinion, and have gone beyond the facts vouched for by evidence. But in a discussion of this kind there are three questions to be borne in mind. Of the two classes of instruments:

1. Which has the greater "*light-grasping*" *power?*

2. Which is more generally *suitable for observatory work?*

3. Which has greater *permanence of optical qualities?*

In regard to the *first question*, it is certain that up to the present limit of size produced, the refractor has the advantage. But in the reflector, the reflecting power of each unit of surface is constant, whatever the size of the speculum, and in the refractor the transmitting power decreases with the thickness of the glass, rendered necessary by increasing size. It is obvious then, that on increasing the size, a stage must be at last reached, when the two become equal to each other. The limit has been estimated to be 35.435 inches, a size not

yet reached by about 9 inches. But object-glasses are slowly gaining in size, and it is not improbable that this limit will sometime be reached.

Suitability for observatory work, depends somewhat on the nature of the work required. For measuring positions, where permanency of mounting is of great importance, the refractor has decidedly the advantage; whereas, for physical astronomy, where a steady image for a time only is required, it may be found that the advantage will be on the side of the future great reflector.

The *question of permanence of optical qualities* is worthy of attention, and here again, the refractor undoubtedly has the advantage. It is very rarely the case that the polish of object-glasses is in any way injured even after many years of continuous use; while specula, whether of metal or of silvered glass, become considerably tarnished after a few years of service.

After considering these abvantages and disadvantages of the two classes of

telescopes, we are led to the following conclusions:

1. At the present day the largest refractor is equal in optical power to the largest reflector. It is more convenient in use, easier to manage, and better adapted to general observatory work. And it enjoys a greater permanence of optical qualities.

2. The reflector will be the great telescope of the future if (1) specula of large diameter can be produced, free from imperfections of curvature and polish; and if (2) increasing difficulties of mounting and manipulation can be overcome. If these latter mechanical difficulties cannot be entirely removed, the refractor will continue to be the "working instrument" in the future, as it has been in the past, although the future reflector may accomplish the grandest results in the domain of physical astronomy.

A TREATISE ON OPTICS;

OR,

LIGHT AND SIGHT,

THEORETICALLY AND PRACTICALLY TREATED,

WITH THE

Application to Fine Art and Industrial Pursuits,

By E. Nugent, C. E.

This Treatise on Optics is intended for all who desire to attain an accurate knowledge of one of the most interesting and useful branches of science. The author has endeavored to steer clear of all abstruse mathematical investigation and formulæ, so as to render the work easily understood by every intelligent reader.

With One Hundred and Twenty-three Illustrations.
12mo., Cloth. Price $1.50.

D. VAN NOSTRAND, Publisher,
23 Murray and 27 Warren Streets, New York.

*** Any book in this Catalogue sent free by mail, on receipt of price.*

VALUABLE

SCIENTIFIC BOOKS,

PUBLISHED BY

D. VAN NOSTRAND,

23 Murray Street, and 27 Warren Street,

NEW YORK.

WEISBACH. A MANUAL OF THEORETICAL MECHANICS. By Julius Weisbach, Ph. D. Translated by Eckley B. Coxe, A.M., M.E. 1100 pages and 902 wood-cut illustrations. 8vo, cloth, ... $10 00

FRANCIS. LOWELL HYDRAULIC EXPERIMENTS—being a Selection from Experiments on Hydraulic Motors, on the Flow of Water over Weirs, and in open Canals of Uniform Rectangular Section, made at Lowell, Mass. By J. B. Francis, Civil Engineer. Third edition, revised and enlarged, with 23 copper-plates, beautifully engraved, and about 100 new pages of text. 4to, cloth, ... 15 00

KIRKWOOD ON THE FILTRATION OF RIVER WATERS, for the Supply of Cities, as practised in Europe. By James P. Kirkwood. Illustrated by 30 double-plate engravings. 4to, cloth 15 00

FANNING. A PRACTICAL TREATISE OF WATER SUPPLY ENGINEERING. Relating to the Hydrology, Hydrodynamics, and Practical Construction of Water-Works, in North America. With numerous Tables and 180 illustrations. By J. T. Fanning, C.E. 650 pages. 8vo, cloth extra, . $6 00

WHIPPLE. AN ELEMENTARY TREATISE ON BRIDGE BUILDING. By S. Whipple, C. E. New Edition. Illustrated. 8vo, cloth, 4 00

MERRILL. IRON TRUSS BRIDGES FOR RAILROADS. The Method of Calculating Strains in Trusses, with a careful comparison of the most prominent Trusses, in reference to economy in combination, etc., etc. By Bvt. Col. William E. Merrill, U. S. A., Corps of Engineers. Nine lithographed plates of illustrations. Third edition. 4to, cloth, ... 5 00

SHREVE. A TREATISE ON THE STRENGTH OF BRIDGES AND ROOFS. Comprising the determination of Algebraic formulas for Strains in Horizontal, Inclined or Rafter, Triangular, Bowstring Lenticular and other Trusses, from fixed and moving loads, with practical applications and examples, for the use of Students and Engineers. By Samuel H. Shreve, A. M., Civil Engineer. Second edition, 87 woodcut illustrations. 8vo, cloth, . . . 3 50

KANSAS CITY BRIDGE. WITH AN ACCOUNT OF THE REGIMEN OF THE MISSOURI RIVER,—and a description of the Methods used for Founding in that River. By O. Chanute, Chief Engineer, and George Morison, Assistant Engineer. Illustrated with five lithographic views and twelve plates of plans. 4to, cloth, . . . 6 00

CLARKE. DESCRIPTION OF THE IRON RAILWAY BRIDGE Across the Mississippi River at Quincy, Illinois. By Thomas Curtis Clarke, Chief Engineer. With twenty-one lithographed Plans. 4to, cloth, ... $7 50

ROEBLING. LONG AND SHORT SPAN RAILWAY BRIDGES. By John A. Roebling, C. E. With large copperplate engravings of plans and views. Imperial folio, cloth, . 25 00

DUBOIS. THE NEW METHOD OF GRAPHICAL STATICS. By A. J. Dubois, C. E., Ph. D. 60 illustrations. 8vo, cloth, ... 1 50

McELROY. PAPERS ON HYDRAULIC ENGINEERING. The Hempstead Storage Reservoir of Brooklyn, its Engineering Theory and Results. By Samuel McElroy, C. E. 8vo, paper, . 50

BOW. A TREATISE ON BRACING—with its application to Bridges and other Structures of Wood or Iron. By Robert Henry Bow, C. E. 156 illustrations on stone. 8vo, cloth, 1 50

STONEY. THE THEORY OF STRAINS IN GIRDERS —and Similar Structures—with Observations on the Application of Theory to Practice, and Tables of Strength and other Properties of Materials. By Bindon B. Stoney, B. A. New and Revised Edition, with numerous illustrations. Royal 8vo, 664 pp., cloth, ... 12 50

HENRICI. SKELETON STRUCTURES, especially in their Application to the building of Steel and Iron Bridges. By Olaus Henrici. 8vo, cloth, ... 1 50

KING. LESSONS AND PRACTICAL NOTES ON STEAM. The Steam Engine, Propellers, &c., &c., for Young Engineers. By the late W. R. King, U. S. N., revised by Chief-Engineer J. W. King, U. S. Navy. 19th edition. 8vo, cloth, ... 2 00

AUCHINCLOSS. APPLICATION OF THE SLIDE VALVE and Link Motion to Stationary, Portable, Locomotive and Marine Engines. By William S Auchincloss. Designed as a hand-book for Mechanical Engineers. With 37 wood-cuts and 21 lithographic plates, with copper-plate engraving of the Travel Scale. Sixth edition. 8vo, cloth, $3 00

BURGH. MODERN MARINE ENGINEERING, applied to Paddle and Screw Propulsion. Consisting of 36 Colored Plates, 259 Practical Wood-cut Illustrations, and 403 pages of Descriptive Matter, the whole being an exposition of the present practice of the following firms: Messrs J. Penn & Sons; Messrs. Maudslay, Sons & Field; Messrs. James Watt & Co.; Messrs. J. & G. Rennie. Messrs. R. Napier & Sons. Messrs J. & W Dudgeon; Messrs. Ravenhill & Hodgson; Messrs Humphreys & Tenant; Mr J. T. Spencer, and Messrs. Forrester & Co. By N P. Burgh. Engineer. One thick 4to vol., cloth. $25 00; half morocco, 30 00

BACON. A TREATISE ON THE RICHARD'S STEAM-ENGINE INDICATOR—with directions for its use. By Charles T. Porter. Revised, with notes and large additions as developed by American Practice; with an Appendix containing useful formulæ and rules for Engineers. By F. W. Bacon, M. E. Illustrated Second edition. 12mo. Cloth $1.00; morocco, ... 1 50

ISHERWOOD ENGINEERING PRECEDENTS FOR STEAM MACHINERY. By B. F. Isherwood, Chief Engineer, U. S. Navy. With illustrations. Two vols. in one. 8vo, cloth, 2 50

STILLMAN. THE STEAM ENGINE INDICATOR—and the Improved Manometer Steam and Vacuum Gauges—their utility and application. By Paul Stillman. New edition. 12mo, cloth, ... 1 00

MacCORD. A PRACTICAL TREATISE ON THE SLIDE VALVE, BY ECCENTRICS—examining by methods the action of the Eccentric upon the Slide Valve, and explaining the practical processes of laying out the movements, adapting the valve for its various duties in the steam-engine. By C. W. Mac Cord, A. M., Professor of Mechanical Drawing, Stevens' Institute of Technology, Hoboken, N. J. Illustrated. 4to, cloth. $3 00

PORTER. A TREATISE ON THE RICHARDS' STEAM-ENGINE INDICATOR, and the Development and Application of Force in the Steam-Engine. By Charles T. Porter. Third edition, revised and enlarged. Illustrated. 8vo, cloth, ... 3 50

McCULLOCH A TREATISE ON THE MECHANICAL THEORY OF HEAT, AND ITS APPLICATIONS TO THE STEAM-ENGINE. By Prof. R. S. McCulloch, of the Washington and Lee University, Lexington, Va. 8vo, cloth, ... 3 50

VAN BUREN. INVESTIGATIONS OF FORMULAS—for the Strength of the Iron parts of Steam Machinery. By J. D. Van Buren, Jr., C. E. Illustrated. 8vo, cloth. . 2 00

STUART. HOW TO BECOME A SUCCESSFUL ENGINEER. Being Hints to Youths intending to adopt the Profession. By Bernard Stuart, Engineer. Sixth edition 18mo, boards, ... 50

SHIELDS. NOTES ON ENGINEERING CONSTRUCTION. Embracing Discussions of the Principles involved, and Descriptions of the Material employed in Tunneling, Bridging, Canal and Road Building, etc., etc. By J. E. Shields, C. E. 12mo. cloth, . . . 1 50

WEYRAUCH. STRENGTH AND CALCULATION OF DIMENSIONS OF IRON AND STEEL CONSTRUCTIONS. Translated from the German of J. J. Weyrauch, Ph. D., with four folding Plates. 12mo, cloth, ... $1 00

STUART. THE NAVAL DRY DOCKS OF THE UNITED STATES. By Charles B. Stuart, Engineer in Chief, U. S. Navy. Twenty-four engravings on steel. Fourth edition. 4to, cloth, ... 6 00

COLLINS. THE PRIVATE BOOK OF USEFUL ALLOYS, and Memoranda for Goldsmiths, Jewellers, etc. By James E. Collins. 18mo, flexible cloth, ... 50

TUNNER. A TREATISE ON ROLL-TURNING FOR THE MANUFACTURE OF IRON. By Peter Tunner Translated by John B. Pearse. With numerous wood-cuts, 8vo, and a folio Atlas of 10 lithographed plates of Rolls, Measurements, &c. Cloth, . . 10 00

GRUNER. THE MANUFACTURE OF STEEL. By M. L. Gruner. Translated from the French, by Lenox Smith, A.M., E.M.; with an Appendix on the Bessemer Process in the United States, by the translator. Illustrated by lithographed drawings and wood-cuts. 8vo, cloth, ... 3 50

BARBA. THE USE OF STEEL IN CONSTRUCTION. Methods of Working, Applying, and Testing Plates and Bars. By J. Barba. Translated from the French, with a Preface by A. L. Holley, P.B. Illustrated. 12mo, cloth. 1 50

SHOCK. STEAM BOILERS; THEIR DESIGN, CONSTRUCTION, AND MANAGEMENT. by William A. Shock, Engineer-in-Chief, U.S.N.; Chief of Bureau of Steam Engineering, U.S.N. 480 pages. Illustrated with 150 woodcuts and 36 full-page plates (20 double). 4to, illustrated, half morocco, ... 5 00

WARD. STEAM FOR THE MILLION. A Popular Treatise on Steam and its Application to the Useful Arts, especially to Navigation. By J. H. Ward, Commander U. S. Navy. 8vo, cloth. $1 00

CLARK. A MANUAL OF RULES, TABLES AND DATA FOR MECHANICAL ENGINEERS. Based on the most recent investigations. By Dan. Kinnear Clark. Illustrated with numerous diagrams. 1012 pages. 8vo. Cloth, $7 50; half morocco, ... 10 00

JOYNSON. THE METALS USED IN CONSTRUCTION: Iron, Steel, Bessemer Metals, etc, By F. H. Joynson. Illustrated. 12mo, cloth, ... 75

DODD. DICTIONARY OF MANUFACTURES, MINING, MACHINERY, AND THE INDUSTRIAL ARTS. By George Dodd. 12mo, cloth, 1 50

PRESCOTT. FIRST BOOK IN QUALITATIVE CHEMISTRY. By Albert B. Prescott, Professor of Organic and Applied Chemistry in the University of Michigan. 12mo, cloth, . . 1 50

PLATTNER. MANUAL OF QUALITATIVE AND QUANTITATIVE ANALYSIS WITH THE BLOW-PIPE. From the last German edition. Revised and enlarged. By Prof. Th. Richter, o the Royal Saxon Mining Academy. Translated by Professor H. B. Cornwall. With eighty-seven wood-cuts and lithographic plate. Third edition, revised. 568 pp. 8vo, cloth, ... 5 00

PLYMPTON. THE BLOW-PIPE: A Guide to its Use in the Determination of Salts and Minerals. Compiled from various sources, by George W. Plympton, C. E., A. M., Professor of Physical Science in the Polytechnic Institute, Brooklyn, N. Y. 12mo, cloth 1 50

JANNETTAZ. A GUIDE TO THE DETERMINATION OF ROCKS; being an Introduction to Lithology. By Edward Jannettaz, Docteur des Sciences. Translated from the French by G. W. Plympton, Professor of Physical Science at Brooklyn Polytechnic Institute. 12mo, cloth, ... $1 50

MOTT. A PRACTICAL TREATISE ON CHEMISTRY (Qualitative and Quantitative Analysis), Stoichiometry, Blowpipe Analysis, Mineralogy, Assaying, Pharmaceutical Preparations Human Secretions, Specific Gravities, Weights and Measures, etc., etc., etc. By Henry A. Mott, Jr., E. M., Ph. D. 650 pp. 8vo, cloth, ... 6 00

PYNCHON. INTRODUCTION TO CHEMICAL PHYSICS; Designed for the Use of Academies, Colleges, and High Schools. Illustrated with numerous engravings, and containing copious experiments, with directions for preparing them. By Thomas Ruggles Pynchon, D. D., M. A., President of Trinity College, Hartford. New edition, revised and enlarged. Crown 8vo, cloth, ... 3 00

PRESCOTT. CHEMICAL EXAMINATION OF ALCOHOLIC LIQUORS. A Manual of the Constituents of the Distilled Spirits and Fermented Liquors of Commerce, and their Qualitative and Quantitative Determinations. By Alb. B. Prescott, Prof. of Chemistry, University of Michigan. 12mo, cloth, . 1 50

ELIOT AND STORER. A COMPENDIOUS MANUAL OF QUALITATIVE CHEMICAL ANALYSIS. By Charles W. Eliot and Frank H. Storer. Revised, with the co-operation of the Authors, by William Ripley Nichols, Professor of Chemistry in the Massachusetts Institute of Technology. New edition, revised. Illustrated. 12mo, cloth, ... 1 50

NAQUET. LEGAL CHEMISTRY. A Guide to the Detection of Poisons, Falsification of Writings, Adulteration of Alimentary and Pharmaceutical Substances; Analysis of Ashes, and Examination of Hair, Coins, Fire-arms and Stains, as Applied to Chemical Jurisprudence. For the Use of Chemists, Physicians, Lawyers, Pharmacists, and Experts. Translated, with additions, including a List of Books and Memoirs on Toxicology, etc., from the French of A. Naquet, by J. P. Battershall, Ph. D.; with a Preface by C. F. Chandler, Ph. D., M. D., LL. D. Illustrated. 12mo, cloth, ... $2 00

PRESCOTT. OUTLINES OF PROXIMATE ORGANIC ANALYSIS for the Identification, Separation, and Quantitative Determination of the more commonly occurring Organic Compounds. By Albert B. Prescott, Professor of Chemistry, University of Michigan. 12mo, cloth, ... 1 75

DOUGLAS AND PRESCOTT. QUALITATIVE CHEMICAL ANALYSIS. A Guide in the Practical Study of Chemistry, and in the work of Analysis. By S. H. Douglas and A. B. Prescott; Professors in the University of Michigan. Third edition, revised. 8vo, cloth, ... 3 50

RAMMELSBERG. GUIDE TO A COURSE OF QUANTITATIVE CHEMICAL ANALYSIS, ESPECIALLY OF MINERALS AND FURNACE PRODUCTS. Illustrated by Examples. By C. F. Rammelsberg. Translated by J. Towler, M. D. 8vo, cloth, ... 2 25

BEILSTEIN. AN INTRODUCTION TO QUALITATIVE CHEMICAL ANALYSIS. By F. Beilstein. Third edition. Translated by I. J. Osbun. 12mo. cloth, ... 75

POPE. A Hand-book for Electricians and Operators. By Frank L. Pope. Ninth edition. Revised and enlarged, and fully illustrated. 8vo, cloth, ... 2 00

UNIVERSITY OF MICHIGAN
3 9015 03502 5975